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STRATIGRAPHY OF THE LATE QUATERNARY RAISED BEACH DEPOSITS IN THE NORTHERN PART OF LANGHOVDE, LÜTZOW-HOLM BAY, EAST ANTARCTICA

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Abstract: Two trenches into a raised beach at the northern part of Langhovde revealed that the beach deposits are clearly divided into two marine sediment layers by an unconformity. Both sediment layers are mainly composed of sand and include *in situ* fossil shells of *Laternula elliptica*. Radiocarbon ages of the fossil shells collected from the upper layer ranged from 5270 ± 60 yBP to 4050 ± 80 yBP without a reservoir correction, and those from the lower layer ranged from 46420 ± 1500 yBP to 32430 ± 270 yBP. The Holocene upper layer is interbedded with deltaic sediments including reworked shell fragments. The unconformity is overlaid with a gravel layer that includes no marine fossils. The gravel layer was deposited under a terrestrial environment during a period of low-stand sea-level. These facts suggest the following: 1) The East Antarctic Ice Sheet retreated from the northern part of Langhovde and a transgression occurred prior to the Last Glacial Maximum (LGM); 2) The Ice Sheet had not re-advanced over the beach of the northern Langhovde even during the LGM; 3) Holocene transgression occurred around 5k yBP, and 4) Minor regression and transgression occurred during the Holocene transgression.

key words: late Quaternary, raised beach, radiocarbon age, East Antarctic Ice Sheet, sea-level

1. Introduction

Ice-free areas scattered along the coast of Antarctica could have been entirely buried by expanded ice sheets during the Last Glacial Maximum (LGM, oxygen isotope stage 2) as suggested by STUIVER *et al.* (1981) and DENTON *et al.* (1991). Recent papers, however, have proposed new interpretations of the LGM glacial expansion around the Antarctic continent (COLHOUN and ADAMSON, 1992; IGARASHI *et al.*, 1995; MORIWAKI and IGARASHI, 1995). The issue is still controversial.

Many raised beaches have been studied in coastal ice-free areas of Antarctica. Deposits and micro-relief of raised beaches have recorded relative sea-level changes since the last glacial retreat of the areas. Furthermore, the fluctuations of relative sea-level suggest isostatic rebound of the unloaded lithosphere caused by the late Quaternary glacial retreat or fluctuations. The late Quaternary glacial fluctuations in Antarctica have been an important issue in Quaternary studies for a long time, and there is still little agreement. The history of glacial fluctuations after the LGM drawn by relative sea-level change on the Antarctic coasts provides important information on the contribution of the Antarctic ice sheet to global sea-level changes during the epoch (BARONI, 1994).

On the ice-free rocks of the Sôya Coast facing Lützow-Holm Bay (Fig. 1), a number of studies have been done on the raised beach deposits and micro-relief since 1957 (YOSHIKAWA and TOYA, 1957; MEGURO *et al.*, 1964; YOSHIDA, 1970, 1973, 1983; OMOTO, 1976, 1977; FUJIWARA, 1973; MORIWAKI, 1974; YOSHIDA and MORIWAKI, 1979; HAYASHI and YOSHIDA, 1994; IGARASHI *et al.*, 1995). Data on the deposits concerning the eleva-

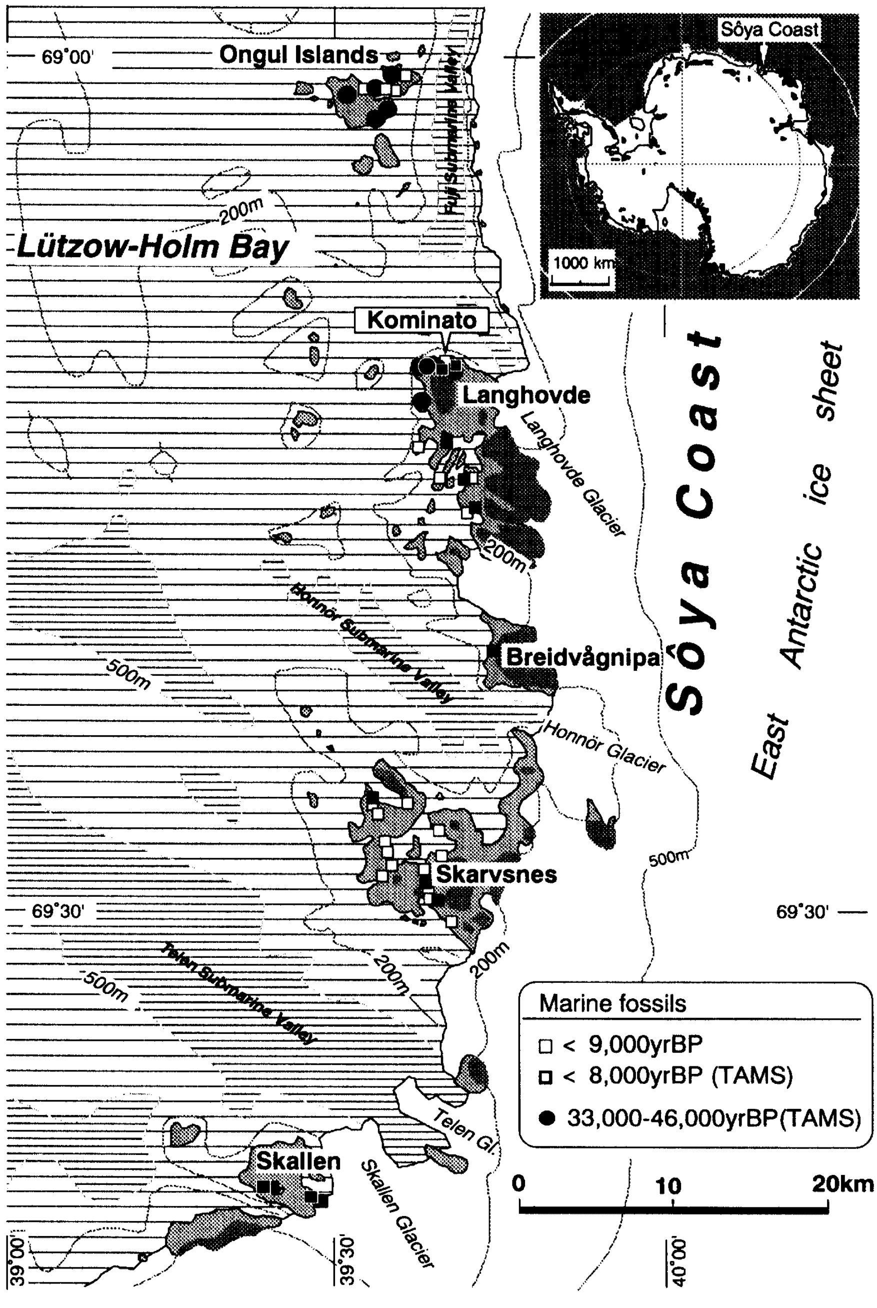

Fig. 1. Localities and classified ^{14}C-dates of marine fossils sampled from raised beaches along the northern part of Sôya Coast. Data sources: Appendix 3 in HAYASHI and YOSHIDA (1994) and IGARASHI et al. (1995).

tion, distribution and ^{14}C age from fossil shells have been accumulated with particular attention to glacial retreat since the LGM and consequent uplift caused by the isostatic rebound.

Raised beach deposits have been reported from sites lower than 25 m asl in the Lützow-Holm bay region. Radiocarbon dates of fossil shells sampled from the raised beaches are classified into two age groups: one is postglacial age between 1 ka and 10 ka and the other is between 22 ka and 34 ka or more (HAYASHI and YOSHIDA, 1994). New interpretation of the age of fossil shells from the region, using the TAMS (Tandetron Accelerator Mass Spectrometry) ^{14}C dating method, was proposed in a recent paper (IGARASHI *et al.*, 1995). They clearly classified the fossil shells into two age groups: the younger group is 3–8 ka and the older is 33–42 ka without the $\delta^{13}C$ and reservoir corrections.

In the northern part of Langhovde, located on the northernmost part of the Sôya Coast, fossil shells of both groups had been sampled at the surface of raised beaches below 8 m asl. Therefore, stratigraphy of the raised beach deposits and sedimentary environment of the fossils of both groups were still unknown. The purpose of this paper is to examine the stratigraphy of raised beach deposits at a beach (Kominato-higashi beach) facing Kominato Inlet located in northern Langhovde by digging trenches to interpret sea-level change during the Late Quaternary.

2. Kominato-higashi Beach, East of Kominato Inlet

Kominato Inlet is an oval-shaped depression probably formed by glacial erosion in the northernmost part of Langhovde, and is connected to Lützow-Holm Bay by a narrow passage (Fig. 2). Langhovde is the second largest ice-free area (50 km^2) in the Lützow-Holm Bay region (Fig. 1). It is bounded on the east by the Langhovde Glacier which drains from the East Antarctic Ice Sheet. Landforms of northern Langhovde are characterized by low-relief erosional surface and a glacial monadnock called whaleback. Mt. Tyôtô, a main monadnock rising to the southwest of Kominato Inlet, has three peaks with elevations of 340 m to 380 m asl. Landforms are totally controlled by lithology and geological structures of bedrock of gneisses, and the land surface is strongly weathered by aeolian salt.

Several raised beaches are developed around Kominato Inlet as a pocket beach. Kominato-higashi beach is the eastern one; its topography is characterized by several step-like beach slope. It occupies a geologically controlled depression with a triangular plane form opened to the inlet. Gathering thawed water supplied from snow patches and an active layer of permafrost, a small stream flows westward on the beach. We decided to do an intensive survey on Kominato-higashi beach, since we recognized that beach sediments were distributed continuously from the present shoreline up to 12 m asl. and there were abundant fossil shells on the raised beach surface. Several ^{14}C ages from fossil shells have been obtained by previous studies on the beach (MORIWAKI, 1974; OMOTO, 1976; NOGAMI, 1977; HAYASHI and YOSHIDA, 1994; IGARASHI *et al.*, 1995).

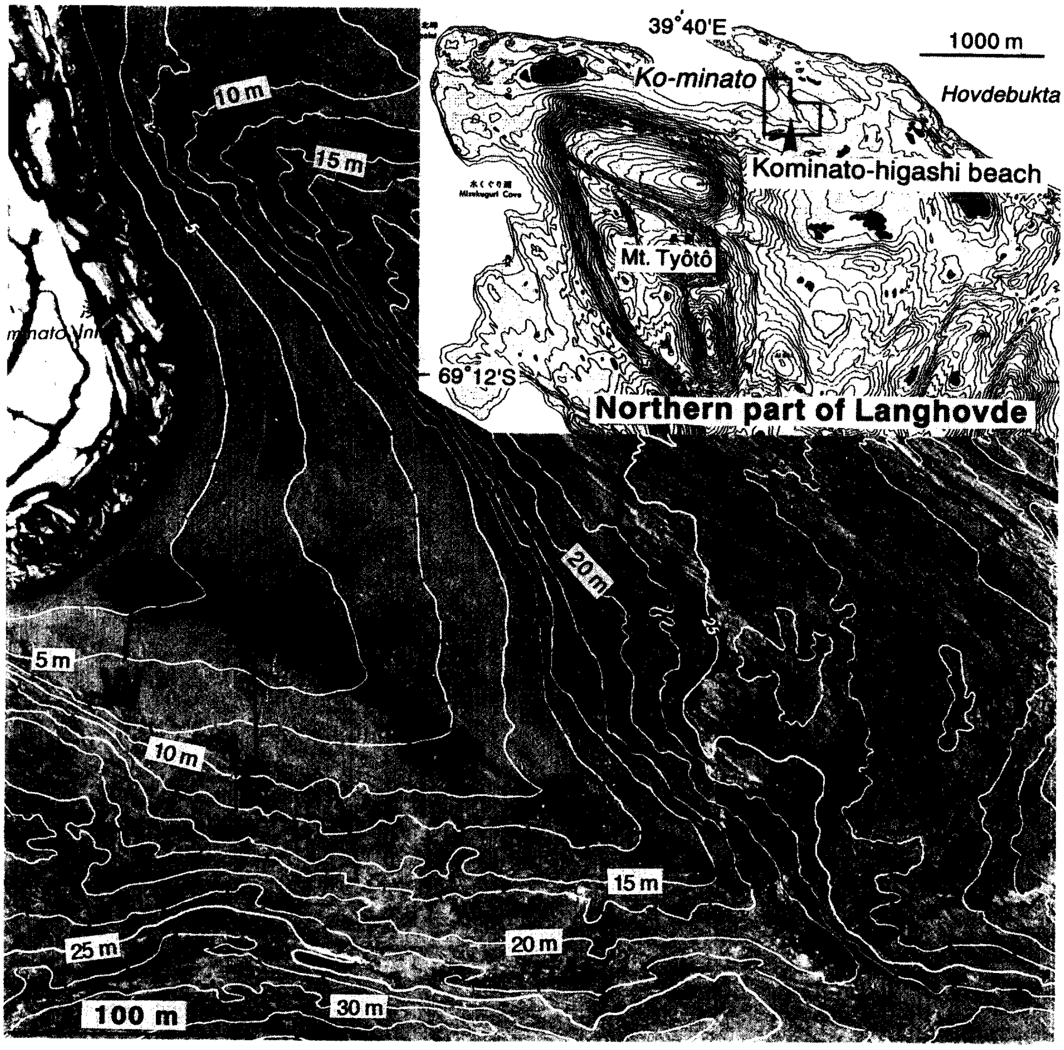

Fig. 2. Topography around Kominato-higashi beach, and sites of the east and west trenches. The base map is published by Geographical Survey Institute of Japan.

3. Stratigraphy and ^{14}C Ages of the Kominato-higashi Beach

We did a trench excavation survey at two sites on the left bank of the mentioned above small stream to explore the stratigraphy of beach deposits on Kominato-higashi beach. Both trenches were dug on the left bank of the stream crossing perpendicularly to the step-like topographies. They were named the E-trench and W-trench, respectively (Fig. 2). They were all excavated by manual shoveling. Altitude was measured by automatic leveling equipment and a five-meter staff, referring to sea-level observed at Kominato Inlet without tidal correction. All ^{14}C ages are reexamined by the $\delta^{13}C$ correction (Table 1). We do not introduce the reservoir effect (*e.g.*, YOSHIDA and MORIWAKI, 1979; OMOTO, 1983) into the ^{14}C ages in this study.

Table 1. Radiocarbon dates of in situ fossil shells obtained from Kominato-higashi beach. All dates are reexamined by the $\delta^{13}C$ corrections, however are not corrected with a reservoir effect.

Trench	Sample No.	Altitude (m asl)	^{14}C age (yr BP)	Method	Code	Material
E-trench	951227-1e	8.58	4900±60	TAMS	Beta-94673	*Laternula elliptica*
	951227-1d	9.22	4350±70	TAMS	Beta-94672	*Laternula elliptica*
	951227-1a	9.22	4920±60	TAMS	Beta-94669	*Laternula elliptica*
	951227-1b	8.90	4850±60	TAMS	Beta-94670	*Laternula elliptica*
	951227-1c	8.50	5270±60	TAMS	Beta-94671	*Laternula elliptica*
	951227-1f	7.68	5000±50	TAMS	Beta-94674	*Laternula elliptica*
	951227-1h	6.45	46420±1500	TAMS	Beta-100347	*Laternula elliptica*
	951227-1i	6.14	35970±410	TAMS	Beta-94675	*Laternula elliptica*
	951227-1k	5.18	39760±600	TAMS	Beta-94676	*Laternula elliptica*
	951227-1m	4.70	42710±920	TAMS	Beta-94677	*Laternula elliptica*
W-trench	951220-1a	4.50	4050±80	TAMS	Beta-100341	*Laternula elliptica*
	951220-1b	4.20	4090±80	TAMS	Beta-100342	*Laternula elliptica*
	951220-1d	3.20	4060±60	TAMS	Beta-100343	*Laternula elliptica*
	951220-1e	2.20	4360±70	TAMS	Beta-100344	*Laternula elliptica*
	951220-1j	2.80	32430±270	TAMS	Beta-100346	*Laternula elliptica*
	951220-1i	2.20	39440±580	TAMS	Beta-100345	*Laternula elliptica*

3.1. E-trench

The east trench (E-trench) was excavated at altitudes between 4.0 m and 9.6 m. The trench was 43 m in length, 1.0 m in width and 1.0 to 1.5 m in depth, which was the depth of the permafrost table or buried gneiss. The log of north wall in the E-trench is shown in Fig. 3.

The trench profile revealed two marine sediment layers (UE and LE) with abundant *in situ* shells composed of *Laternula elliptica* and unbroken shells of *Adamussium colbecki*. The marine layers are separated by a fluvial gravel layer (ME) into upper and lower layers. The boundary between the lower marine layer and the fluvial layer shows a clear unconformity. These sediment layers are obliquely cut by subaerial processes

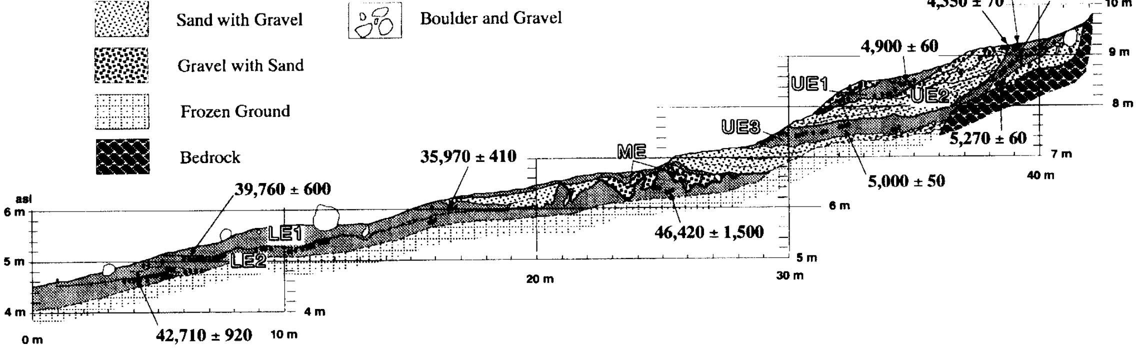

Fig. 3. Profile of the E-trench in the Kominato-higashi beach. The location is shown in Fig. 2.

that exposed them onto the surface. Most of the layers are composed of sorted fine- to medium-grained sand with granule- or pebble-size gravel, and are subdivided into several sublayers with many bedding planes.

1) Lower Layer (LE)

The thickness of LE is unknown because further excavation was obstructed by the permafrost table. The LE was probably deposited on a place higher than 7 m above present sea-level, however the higher part of it might have been removed by subsequent erosion. The LE is subdivided into two sublayers (LE1 and LE2). LE2 is the lower layer, composed of fine- to medium-grained sand with *in situ* fossil *Laternula elliptica*. ^{14}C ages range from 46420±1500 to 39760±600 yBP.

LE1, conformably overlaying LE2, is composed of coarser sand ranging from medium to coarse-grain. The upper part of the LE1 is interbedded with pebble- to cobble-size gravel beds. The LE1 contains in situ fossil shells, one of which was dated 35970±410 yBP.

2) Middle Layer (ME)

The ME overlies the LE with rugged unconformity. It is composed of cobble- to boulder-size subangular gravel without any fossil shell, even fragments. It seems to include cut-and-fill deposits suggesting a terrestrial environment.

3) Upper Layer (UE)

The UE is subdivided into three sublayers (UE1-3). The lowest sublayer UE3 abuts on bedrock at least above 7.5 m asl. The lower part of UE3 does not yield *in situ* fossil shells, but reworked shell fragments are interbeded in coarse-grained sand beds with cross-lamination. Pebble- to cobble-size gravel is also scattered on the layer bottom. This part is inferred to have been laid down in very shallow water such as in a river mouth.

The upper part of UE3 is composed of fine to medium-grained sand with abundant *in situ Laternula elliptica* fossils. Several boulders dropped from the upper slope are also observed in the fine beach deposits near the bedrock slope. ^{14}C ages of fossil shells range from 5270±60 to 4850±60 yBP. The higher part of UE3 was flattened by marine or fluvial abrasion during the UE2 period.

UE2 unconformably overlies UE3, and is composed of medium to coarse-grained sand with granule to pebble size gravel. The UE2 yields only reworked shell fragments in coarse-grained sand beds with cross-lamination. This sublayer was probably laid down in a river mouth the same environment as the lower part of UE3. Forming a terrace scarp, unsorted angular to sub-angular pebble-size gravel is laid on UE2. *In situ Laternula elliptica* fossils occur just below the beach surface which obliquely cuts the sediment layers. The shell was dated 4350±70 yBP in ^{14}C age. This age is younger than that of fossils yielded in UE1 as shown later. Although there is plenty of room for interpretation, we infer one of the possible reasons for it as follows: the shells had not lived in the UE2 deposits but lived on an abraded sea bottom composed of UE2 after a period of UE1 deposition.

UE1, overlaying UE2, is composed of medium-grained sand with granule- to pebble-size gravel. Unsorted angular to sub-angular pebble gravel is laid on UE1 and forms a terrace scarp the same as in the case of UE2. The UE1 includes *in situ* fossil shells, one of which was dated 4900±60 yBP. This ^{14}C age is inconsistent with stratigraphy of UE1 and UE2.

3.2. W-trench

The west trench (W-trench) was excavated at 60 m seaward (west) of the E-trench; its altitudes, ranging from 0.8 m to 5.1 m, were lower than the E-trench. The trench was 30 m in length, 1.0 m in width and 0.5 to 1.5 m in depth. The depth was controlled by the permafrost table or buried gneiss. The log of north wall in the W-trench is shown in Fig. 4. The deposits are divided into two sediment layers (UW and LW) with several bedding planes by an unconformity. The sediment layers are composed of well-sorted fine to medium-grained sand with granule- or pebble-size gravel, and yield abundant fossil shells (*Laternula elliptica*) buried in their living positions. Such facies and *in situ* marine fossils suggest that most of the beach deposits were formed by the marine process.

1) Lower Layer (LW)

The lower layer is subdivided by its facies into two sublayers (LW1 and LW2). The lower layer LW2 is composed of medium-grained sand with in situ fossil shells. The ^{14}C age of one of these shells is 39440±580 yBP. Underlying bedrock appeared at an altitude of 1.3 m. LW1 conformably overlies LW2, and is composed of medium to coarse-grained sand with pebble size gravel. The upper part of LW1 shows deltaic foreset structure. The ^{14}C age of *in situ* fossil shells collected from LW1 is 32430±270 yBP.

2) Upper Layer (UW)

The upper layer is subdivided into three sublayers (UW1-3). UW3, the lowest sublayer, overlies unconformably on LW1 and is composed of fine- to medium-grained sand with scattered pebble- to boulder-size gravel at the bottom. This gravel layer including boulders at the bottom can be correlated to ME in the E-trench. Abundant *in situ* fossil shells are observed in the sandy layer. The ^{14}C age of one of the shells indicates 4360±70 yBP.

UW2, unconformably overlaying UW3, is composed of medium- to coarse-grained

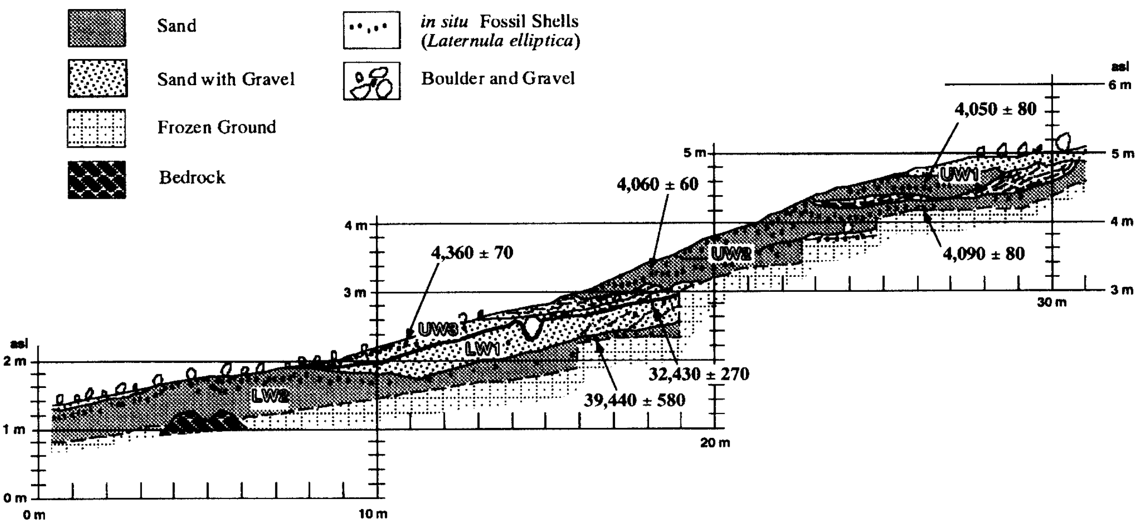

Fig. 4. Profile of the W-trench in the Kominato-higashi beach. The location is shown in Fig. 2.

sand with granule- to cobble-size gravel. The lower part of UW2 does not yield in situ fossils, but reworked shell fragments are interbeded in coarse-grained sand and gravel layers with cross-lamination. This part is considered to have been laid down in a fluvial environment such as a river mouth. Other parts of UW2 contain abundant in situ fossil shells, two of which were dated 4090±80 and 4060±60 yBP.

UW1, which scoured the upper part of UW2, is composed of medium-grained sand with granule-size gravel. The lower part of UW1 yields only reworked shell fragments included in coarse-grained sand and gravel layers with cross-lamination. The upper part of UW1 includes in situ fossil shells, one of which was dated 4050±80 yBP.

4. Discussion of Glacial Fluctuation and Relative Sea-level Change Before and After the LGM, Deduced from the Stratigraphy of Marine Sediments

The lower layers of marine sediments (LE and LW) are subdivided by their facies into sublayers that are composed of beach sand and include *in situ* fossil shells of *Laternula elliptica*. TAMS ^{14}C ages of these fossils ranged from 46420±1500 to 32430±270, from bottom to top of the lower layers. This progressive radiocarbon-age decrease suggests that a transgression occurred during the last interstadial prior to the LGM. The marine sediment layers have not been disturbed by ice sheet loading, and extremely fragile shells of in situ fossils also have not been destroyed by ice sheet loading. These facts suggest that the East Antarctic Ice Sheet 1) retreated from the northern part of Langhovde, and the transgression occurred, prior to the LGM; and 2) has not re-advanced over these sediments since that time, although the locations of the ice margin during the LGM remain unknown, as formerly suggested by YOSHIDA and MORIWAKI (1979), YOSHIDA (1983) and IGARASHI *et al.* (1995).

The upper part of the lower layers was eroded by a fluvial process that formed small channels in the lower layers with overlying fluvial sediments composed of coarse sand and gravel. The fluvial process appears to have been more active than present meltwater activity, because the present meltwater does not transport boulder gravels in the area. The fluvial process may have occurred during the early Holocene prior to the younger transgression indicated by the upper layer of marine sediments.

The upper layers of marine sediments (UE and UW) are composed of fine marine sand with interbedded coarse deltaic sand and gravel. *In situ* fossil shells of *Laternula elliptica* occurred in the marine sand layer and partially in the deltaic sediments. The deltaic sediments also include reworked shell fragments. ^{14}C ages of the *in situ* shells are 5270±60 to 4050±80 yBP. from bottom to top of the upper layers. The upper layer clearly indicates Holocene transgression around 5 ka ^{14}C age without a reservoir correction. Interbedding deltaic sediments with reworked shell fragments suggest that minor regression(s) occurred during the Holocene transgression.

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